NORTHROP GRUMMAN

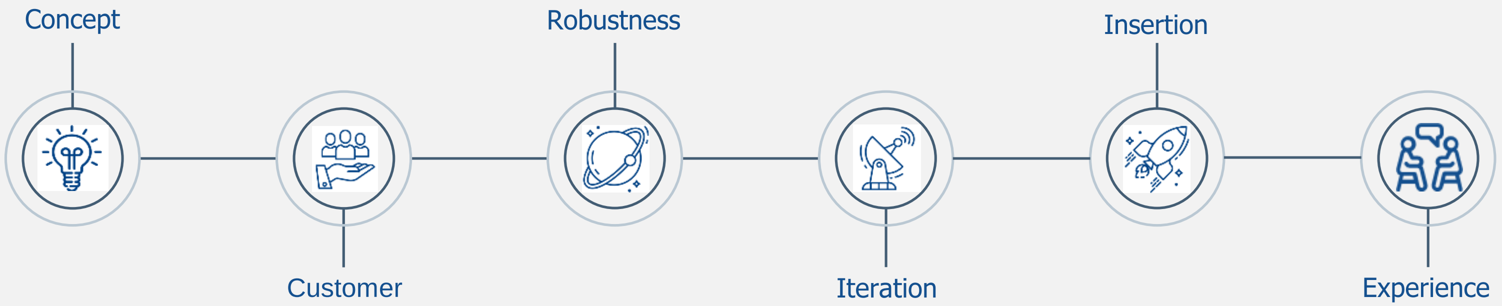
Crossing 'the Valley of Death' of Technology Development

From Technology Readiness Level 4 through 6

Dr. D. Tan

2022.02.08

Outline


Concept
Customer
Robustness
Iteration
Insertion
Experience

Recap of the TRL (NASA, last updated Oct. 28, 2012)

NORTHROP GRUMMAN

Technology Readiness Level

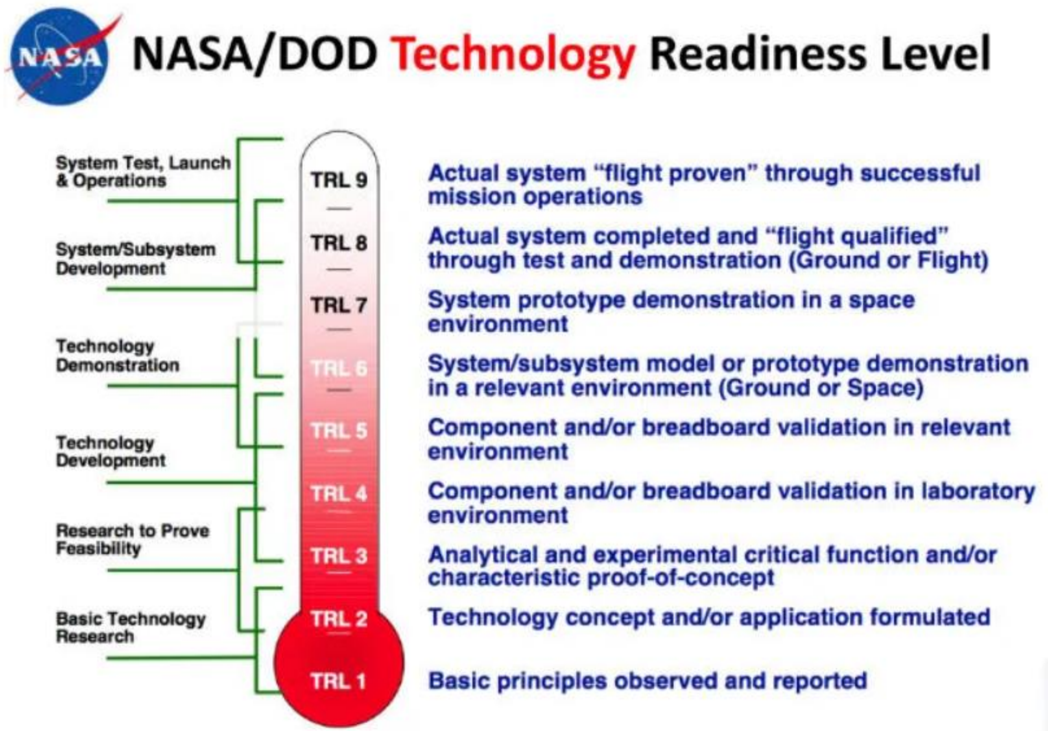
Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.

When a technology is at TRL 1, scientific research is beginning and those results are being translated into future research and development. TRL 2 occurs once the basic principles have been studied and practical applications can be applied to those initial findings. TRL 2 technology is very speculative, as there is little to no experimental proof of concept for the technology.

When active research and design begin, a technology is elevated to TRL 3. Generally both analytical and laboratory studies are required at this level to see if a technology is viable and ready to proceed further through the development process. Often during TRL 3, a proof-of-concept model is constructed.

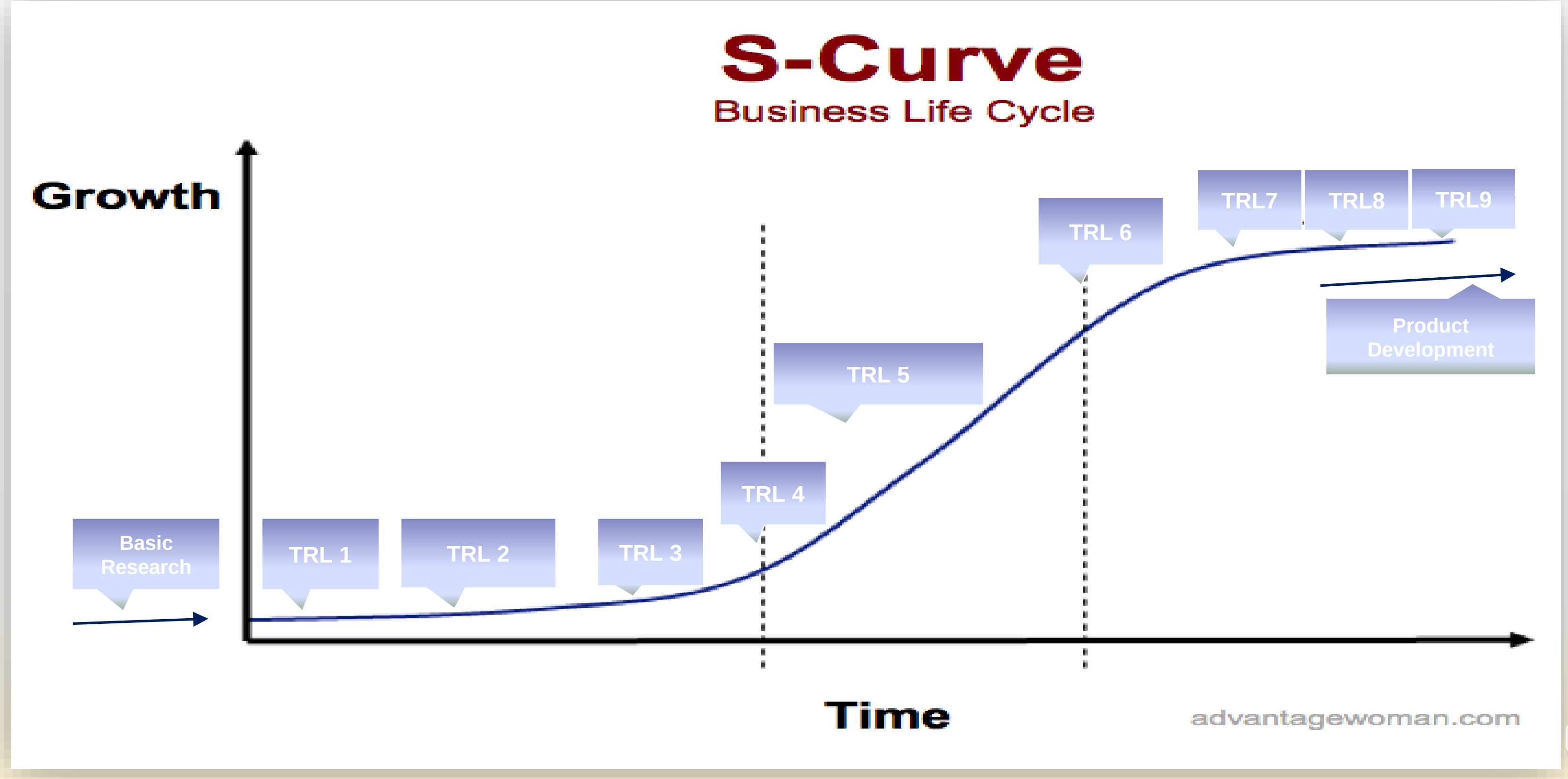
Once the proof-of-concept technology is ready, the technology advances to TRL 4. During TRL 4, multiple component pieces are tested with one another. TRL 5 is a continuation of TRL 4, however, a technology that is at 5 is identified as a breadboard technology and must undergo more rigorous testing than technology that is only at TRL 4. Simulations should be run in environments that are as close to realistic as possible. Once the testing of TRL 5 is complete, a technology may advance to TRL 6. A TRL 6 technology has a fully functional prototype or representational model.

TRL 7 technology requires that the working model or prototype be demonstrated in a space environment. TRL 8 technology has been tested and "flight qualified" and it's ready for implementation into an already existing technology or technology system. Once a technology has been "flight proven" during a successful mission, it can be called TRL 9.

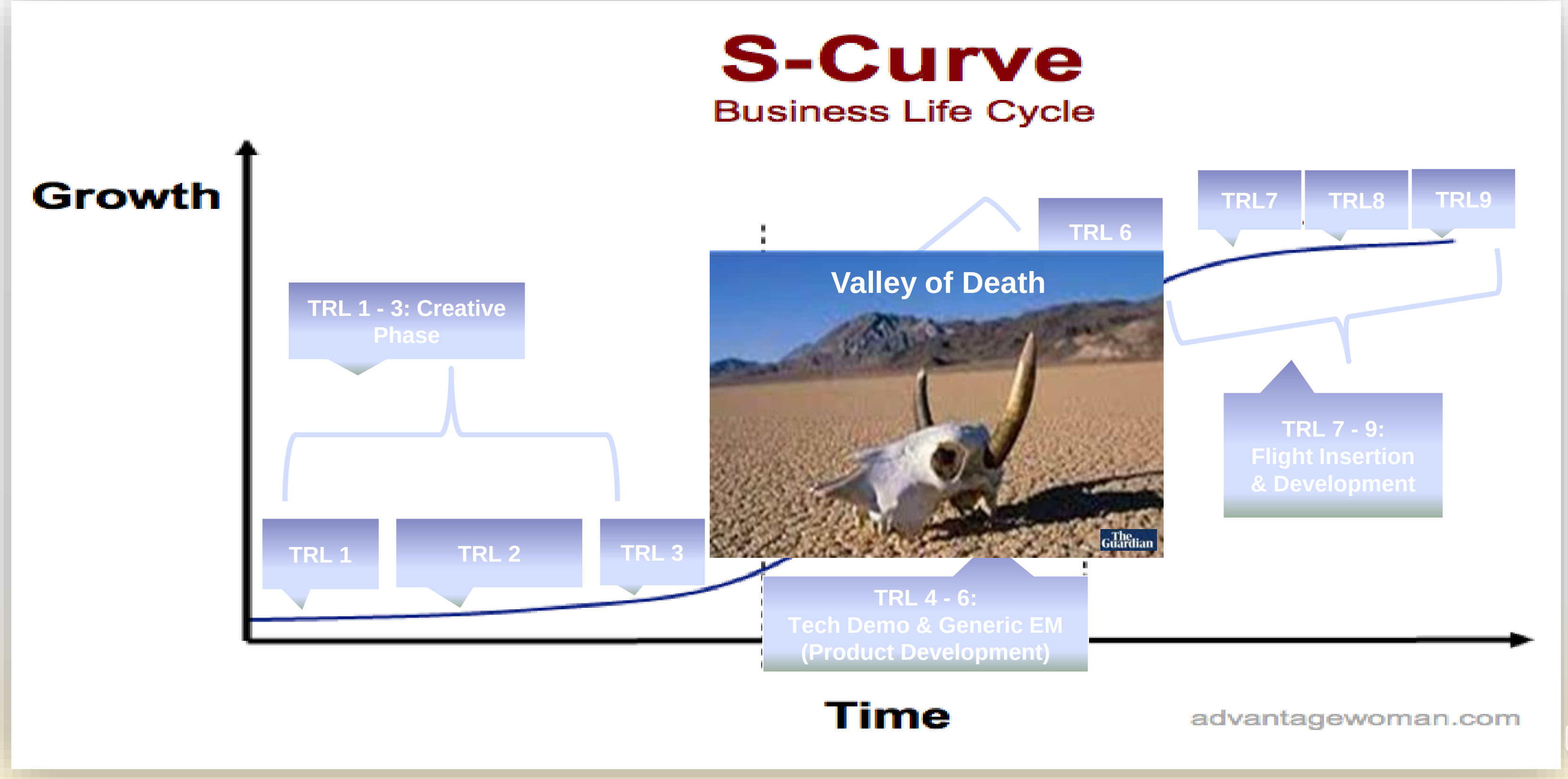


en.wikipedia.org/wiki/Technology_readiness_level

The Innovation S-Curve and the TRLs



'The Valley of Death'



‘The Valley of Death’

- Idea: Developing a technology from initial conception to a major flight program insertion is a daunting task even if you have a brilliant idea to start with
- TRL 1 – 3: Creative Phase
  - Where you or your team members have some brilliant ideas and can quickly validate with simulations or PoC boarding efforts
- TRL 7 – 9: Flight Insertion & Product Development Phase
  - Where you succeed in technology insertion and it is now an engineering effort to further develop to flight
- TRL 4 – 6: Tech Demo Phase
  - Where many bright ideas cannot mature through TRL 4 - 6 even after successfully making through TRL 1 - 3 on IRAD
- People frequently refer the process of making from TRL 4 through 6 “the valley of death of technology development”

‘The Valley of Death’

The Valley of Death phenomena are due to the following factors

1. Technical

1) The idea cannot work after all

2) More vigorous ‘testing’ unveils latent problems

3) The smart idea requires a lot of ‘moving parts’ to implement

4) The idea works, but it is hard to adapt for practical apps

5) “The solution is too complex” – Simplicity is always a beauty

6) The technology is not robust enough for practical apps – p/m sensitivity

‘The Valley of Death’

NORTHROP GRUMMAN

The Valley of Death phenomena are due to the following factors

2. ‘Political’

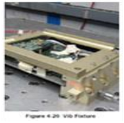
1. Having a hard time to obtain insertion – “the killer app”

2. Inability to secure sufficient funding for a generic EM

3. The step function in EM funding was too hard to justify

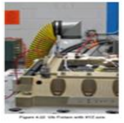
4. People prefer to reuse EM than funding EM testing, for instance

Customer: Benefits, Support & Satisfaction



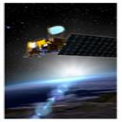
Customer

- Internal
- External



Benefits

- Lower cost
- Higher efficiency
- Smaller mass
- Smaller real estate
- Shorter development cycle
- Short lead time
- Early delivery



S/C Efficiency

- Smaller power size
- Smaller thermal removal system size
- Smaller battery size
- Smaller solar array size

Customer: Support

NORTHROP GRUMMAN

On time delivery of program contractual deliverables

- Monthly status/TIMs/Reviews/Final review and final report
- Working hardware for show-n-tell (Demo)
- Supports above and beyond contractuals
- Early reports on potential problems

Support to keep the program sold/for new opportunities

- Tutorials to help them to understand in simple terms, enabling them to communicate more effectively in their community
- Background informational materials for the customer to sell the program
- On call for consultation as always

Customer: Satisfaction

Customer Satisfaction

No business as usual

On time delivery crucial

Would he/she come back again?

Strive for a “Wow” factor

Working hardware ‘in hand’ more convincing

HONORS AND AWARDS

EXCEPTIONAL ENGINEER

Dong Tan Honored with Engineering Award

ELIZABETH RUITERMAN

Regarded by peers and management alike as an outstanding engineer and leader, Aerospace Systems' (AS) Dr. Dong Tan was selected to receive the Asian American Engineer of the Year Award (AAEOY) at this year's conference Feb. 27. He joins two other Northrop Grumman engineers selected for recognition by the Chinese Institute of Engineers: Roger Fuji (Information Systems) and Melissa Sandlin (Electronic Systems).

A staff manager within the Mixed-Signal and Power Center, "Dong is our distinguished engineer and product champion for power conversion, control/drive electronics and electrical power systems," said Clayton Kau, AS sector vice president, Space & Defense Products. "He is also a company resource and discipline lead to help resolve power converter issues for our entire company."

Known as a technical lead among company ranks, Tan has earned high marks from Ted Nye, a director in AS. "Dong mentors our younger engineers and interacts regularly with university students. Because of his leadership style, his staff is motivated to solve many challenging problems," said Nye.

Citing his significant contributions to technology development and engineering enhancement in power electronics, Professor Yan-Fei Liu of Queen's University in Kingston, Canada, said Dong is an exceptional role model for young engineers and engineering students.

Juan Rivera, a Space Systems Division technology director, said Dong is a great representative of the engineering staff at Space Park, Calif., and of the innovations that are produced.

Tan's resume reflects numerous awards including sector patent and innovation awards, an Institute of Electrical and Electronics Engineers (IEEE) award and an award for technical excellence and creativity from the Mix Foundation (recently renamed the Tec Foundation). His work on high-efficiency forward converters was cited by the IEEE in naming Tan to the Class of 2007 Fellows.

Prior to joining the company, Tan worked for a commercial company where his team developed the world's first high-power audio amplifier powered by a switching power supply, resulting in a product line that has become the company's major revenue producer.

He is a principal author of more than 25 peer-reviewed technical papers and has served on a variety of boards in such industry organizations as the IEEE Power Electronics Society, the National Science Foundation and the Canadian Natural Science Research Council. Since joining the company in 1995, Tan has garnered four patents for Aerospace Systems.

Nationally recognized for his expertise in power conversion, Tan has given professional, educational seminars on cutting-edge technologies for power conversion at leading conferences. In 2004, he was on the National Science Foundation review team on a site visit to the Center of Excellence for Power Electronics Systems, a consortium of more than seven educational institutions led by Virginia Tech.

"In looking at the roster of outstanding recipients nationwide, I am truly humbled to be honored with this award," said Tan. "I would like to share this with my colleagues with whom I have had the privilege to work."

The AAEOY Award is the only program of its kind in the United States. It is a platform for recognizing outstanding Asian American professionals for their personal achievements as well as significant contributions in academia, public service and corporate entities. Many of the recipients bring about critical breakthroughs in science and technology, often with lasting and global impacts.

Robustness of New Technology

Photo from Internet

A simple solution to a complex problem:
The highest form of engineering innovation

Photo from Internet

Robustness of New Technology

NORTHROP GRUMMAN

Novelty is the name of the game for innovation

But it has to be balanced with the robustness

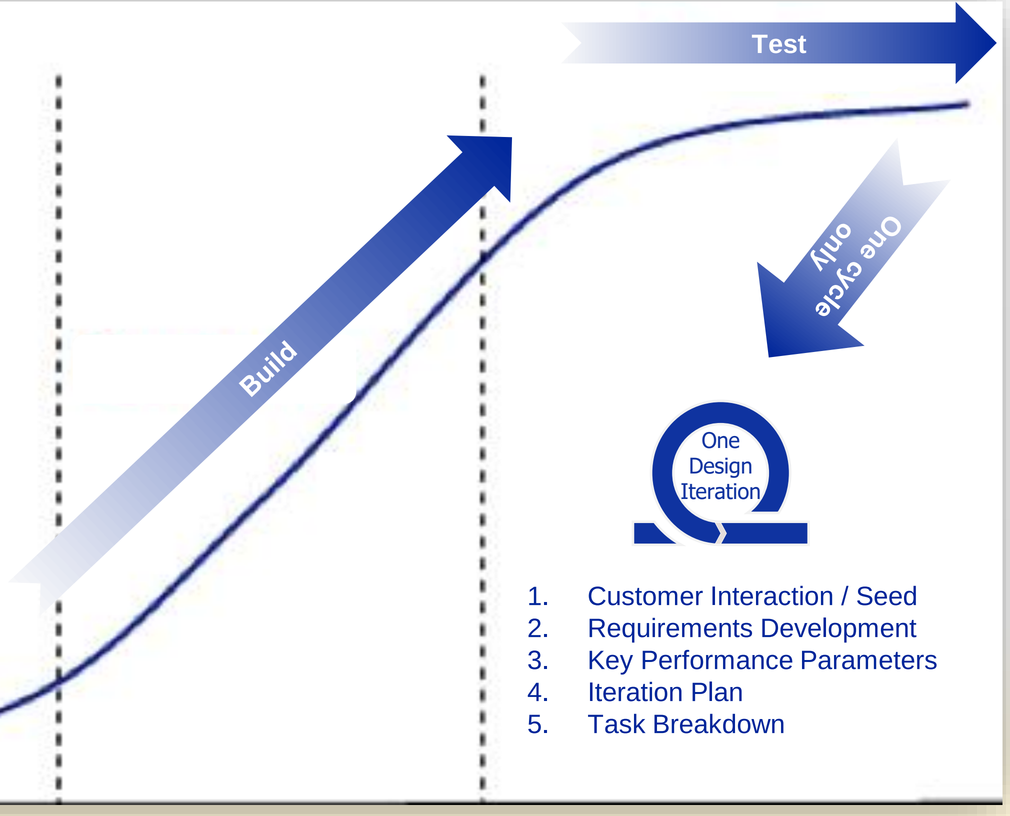
Robustness is critical for your performance on the TD and for eventual technology insertion

Overly complex solutions tend to have problems later on

Prefer a converter topology that is hard to kill switching devices over one with a bit higher efficiency, but less robust

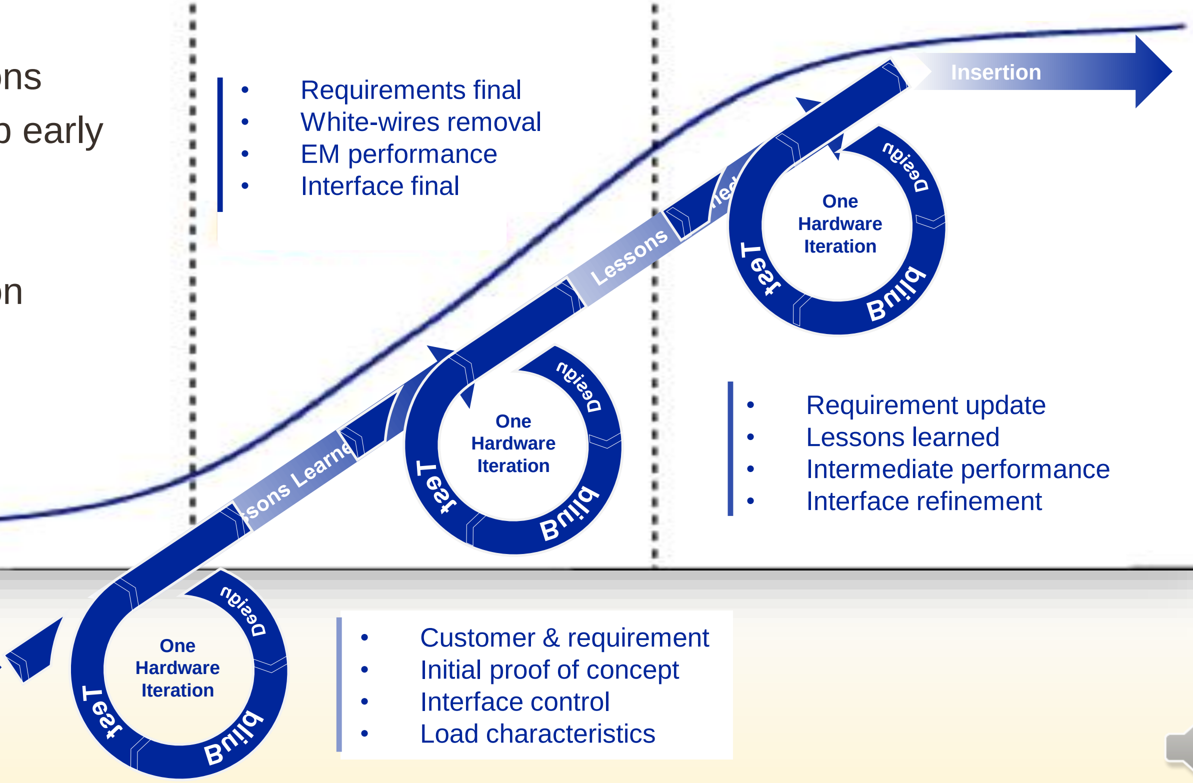
Traditional Development Cycle

- Typical programs have one design cycle
  - One hardware iteration
  - Latent escapes show up late
  - High technical risk
  - High schedule risk
  - Low customer satisfaction



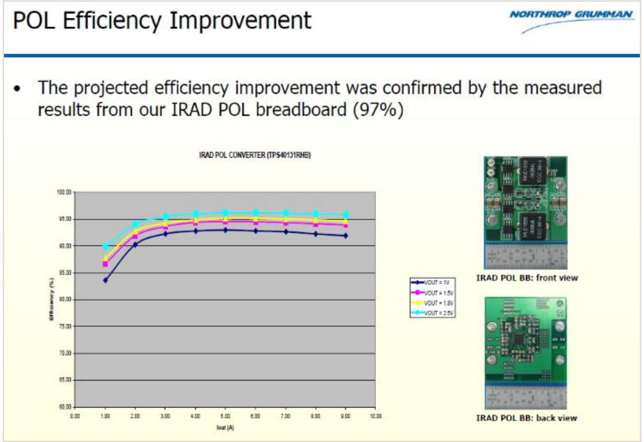
Preferred Approach

- Advantages
  - – Multiple hardware iterations
  - – Latent escape(s) show up early
  - – Low technical risk
  - – Low schedule risk
  - – High customer satisfaction
- Challenges
  - Cost impact
  - Schedule challenge



Hardware Iteration and Delivery

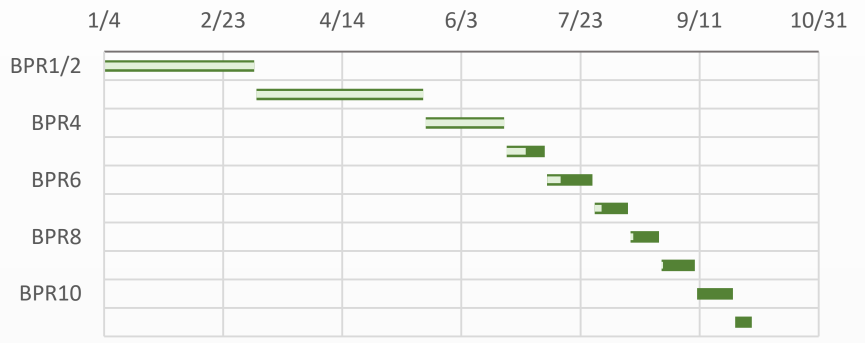
- Hardware iteration is an effective way to discover latent design drawbacks for a new technology or product
- Hardware iteration combines design skills with design processes early in the development cycle
- Early successful hardware iterations (and deliveries) demonstrate your command of the new technology
- Hardware iterations enhance customer satisfactions
- Provide your customer with real data to keep the program “sold” in his or her community

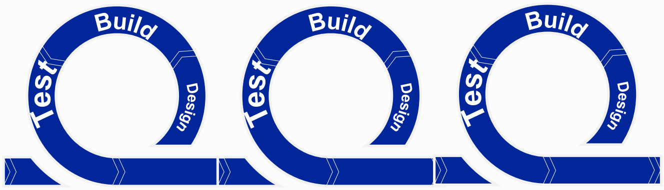


APOL POL first hardware iteration produced an efficiency of 97%

Waterfall vs. Agile (Iterative) Processes

- Agile process originated from the software engineering where iteration (spiral) is the ‘king’ and one iteration does not require a lot of funding
  - You can remote update software (Use your customer for Alpha- and Beta-runs)
  - Updates do not cost much





- Organization planed
- Waterfall activities
- Latent risks
- Inflexible

- Customer focused
- Multiple iterations
- Early risks
- Agile

Challenges for Multiple Iterations (Agile Hardware)

- **Major challenges for hardware iteration**
  - **Cost**
    - Focus on robust technologies
    - Build a strong technical team
    - Share success with a can-do spirit
  - **Parts**
    - Commercial parts in early stage
    - Flight like parts – up-screening
    - Form, fit, or/and function to flight

Ability to execute each hardware iteration in a timely fashion is the key

Insertion Advocacy is a Beautiful Thing

Leverage previous successful insertions / designs

- Working hardware is a lot of more convincing
- ‘Word of Mouth’ in the customer community is golden

Insertion Advocacy

- Sell, sell, sell, …
- Latch onto opportunities faced by an exiting design
- Offer performance / SWaP improvement as an enabler

Address user “adoption anxiety”

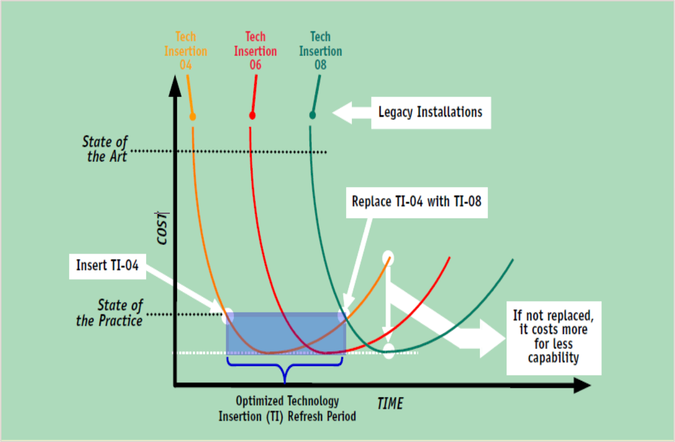
- Building a strong business case with $ signs
- Present direct and derived benefits

Robustness for qual, mfg and test

- Engage them early in the TD phases
- Perform key WCA for representative and stressing cases as early as possible

Insertion: Optimum Insertion Point

- The technology development time vs. cost curve illustrate best time for insertion
- Open system approach (product line P/L) drives down the cost which enables more frequent insertions
- Customer involvement facilitates the process



www.navy.mil

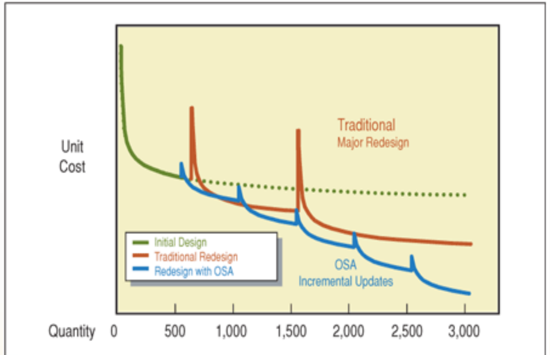


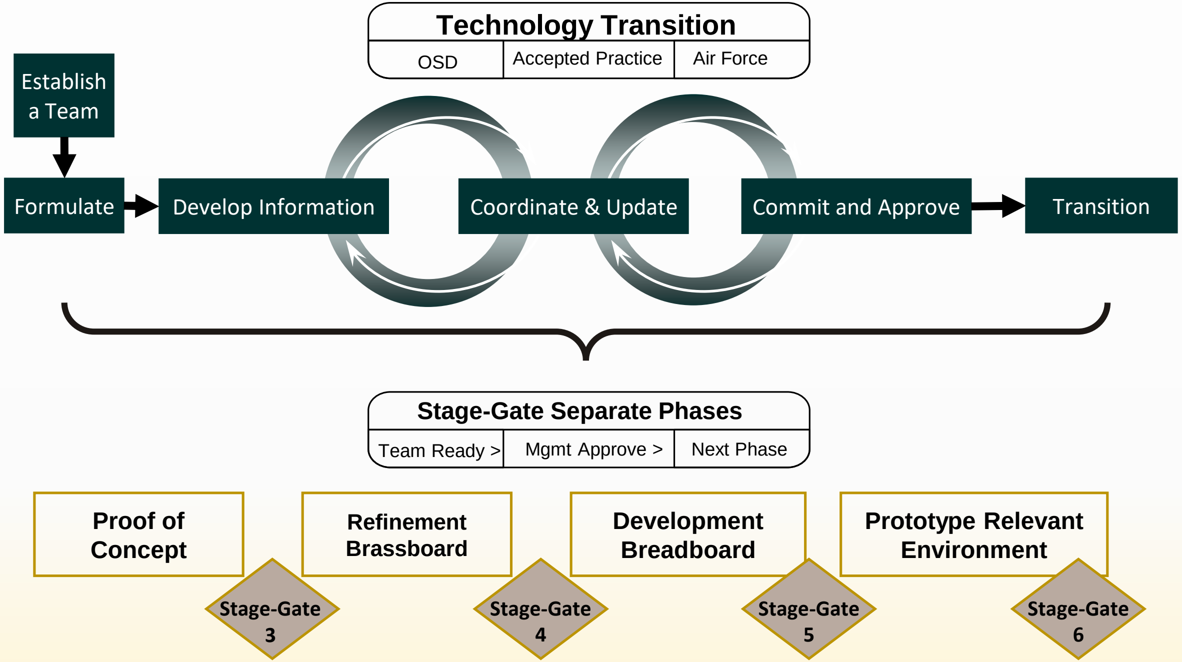
Figure 2

The cost of technology changes in open standards architectures (OSA) is significantly less than proprietary architectures. (Source: DoD Open Systems Joint Task Force.)

www.cotsjournalonline.com

Insertion: Follow a Plan

- Technology Transition Process Iterates Within Each Stage, as defined below, in “TDTS Guide,” by the US Air Force



Insertion: Risk

NORTHROP GRUMMAN

Risk management needs to involve your customer for general approach and top-level plan / architecture

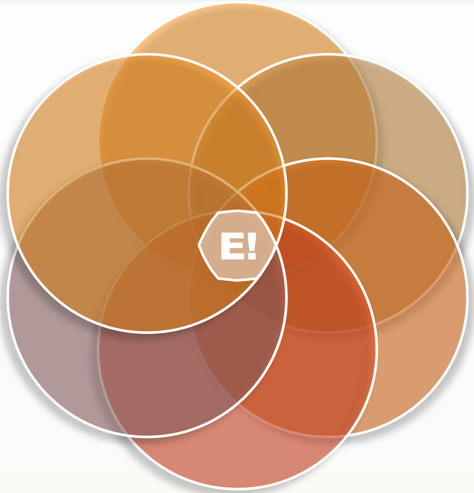
- Avoidable and transferable risk items

Changing business landscape – competition with new products or technologies, need to update business case

- Read, read, read, …

Schedule compression vs. ability to execute

- Good rule of thumb – Compress one month for a 12-month schedule



Product line vs. point design

- Always a trade-off, know where to stop

Cost – especially FFP, funding profile volatility

- Volatility in funding profile impacts execution

Technical unknown unknowns

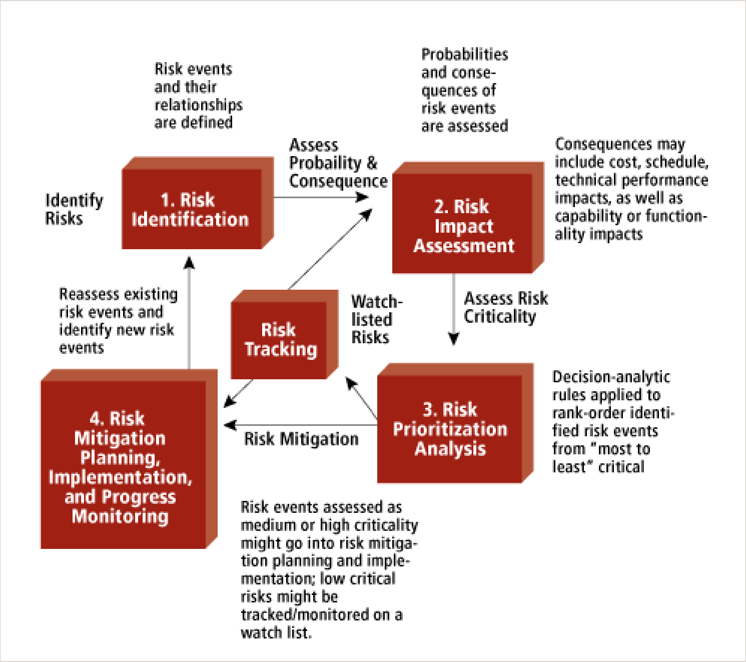
- Unintended consequences, unknown unknowns

Insertion: Risk

- Risk Management

Probability		Impact: Very Low 1	Low 2	Medium 3	High 4	Very High 5
Very High	5	5	10	15	20	25
High	4	4	8	12	16	20
Medium	3	3	6	9	12	15
Low	2	2	4	6	8	10
Very Low	1	1	2	3	4	5

www.pqmslimited.com



www.mitre.org


ossin
the
h Va
for
hnol
elop
unsplash.com

Ranger Timeline

01

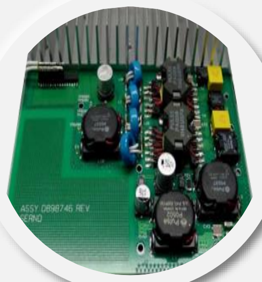
PoC (Cycle)

Ranger CTPS started with a breadboard to demonstrate achievable efficiency/emmision

03

Brassboard (Cycle)

A brassboard was built on program with drive the RF amplifier with reduced noise



02

Breadboard (Cycle)

A breadboard was built on program to demonstrate achievable size/emiision reduction

04

EM (Cycle)

A EM was built on program before the Alph-run for production

NORTHROP GRUMMAN

Recognitions

The CTPS technology was licensed to a major telecom company!
The patent earned a Distinguished Patent Award!

Wes Bush hosted a special luncheon to honor the development team!

TS21 PPU and Propulsion Subsystem Timeline

01

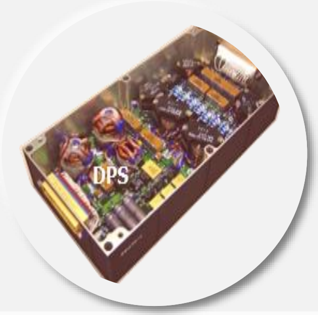
PoC (Cycle)

TS21 started with a high-fidelity breadboard with a coupling test at NASA GRC

03

Brassboard (Cycle)

A EM was built on program that drove the X3 thruster and DCIU for autonomous operation



P&C

02

Brassboard (Cycle)

A brassboard was built on program to demonstrated full funcntionality

04

EM (Cycle)

An EM was built on program to complete full qualification at AFRL under vacumm cahmber

Recognitions

NORTHROP GRUMMAN

TacSat-2 (TS21) PPU earned JANNAF Propulsion Achievement Award for 'One of a kind, all-US built propulsion system' in 2007!

It is still called 'the best PPU' (with autonomy) after so many years by experts in the field

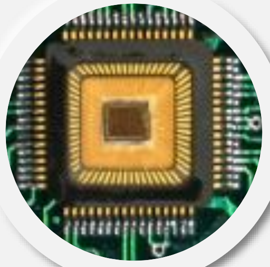
Recognitions

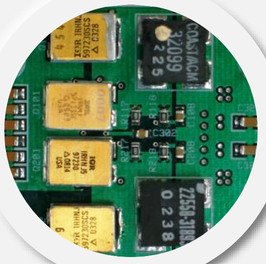
TacSat-2 (TS21) spacecraft design team earned AIAA Space System Achievement Award in 2009!

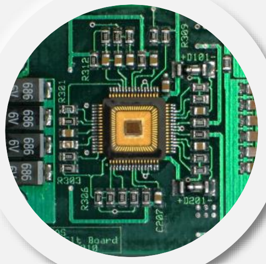
APOL Timeline

01
PoC (Cycle)
APOL started with an idea and a bloock diangram on IRAD

03
Brassboard (Cycle)
A brassboard was built on CRAD with significant customer satisfaction







02
Breadboard (Cycle)
A breadboard was built on IRAD to demonstrated improved performance

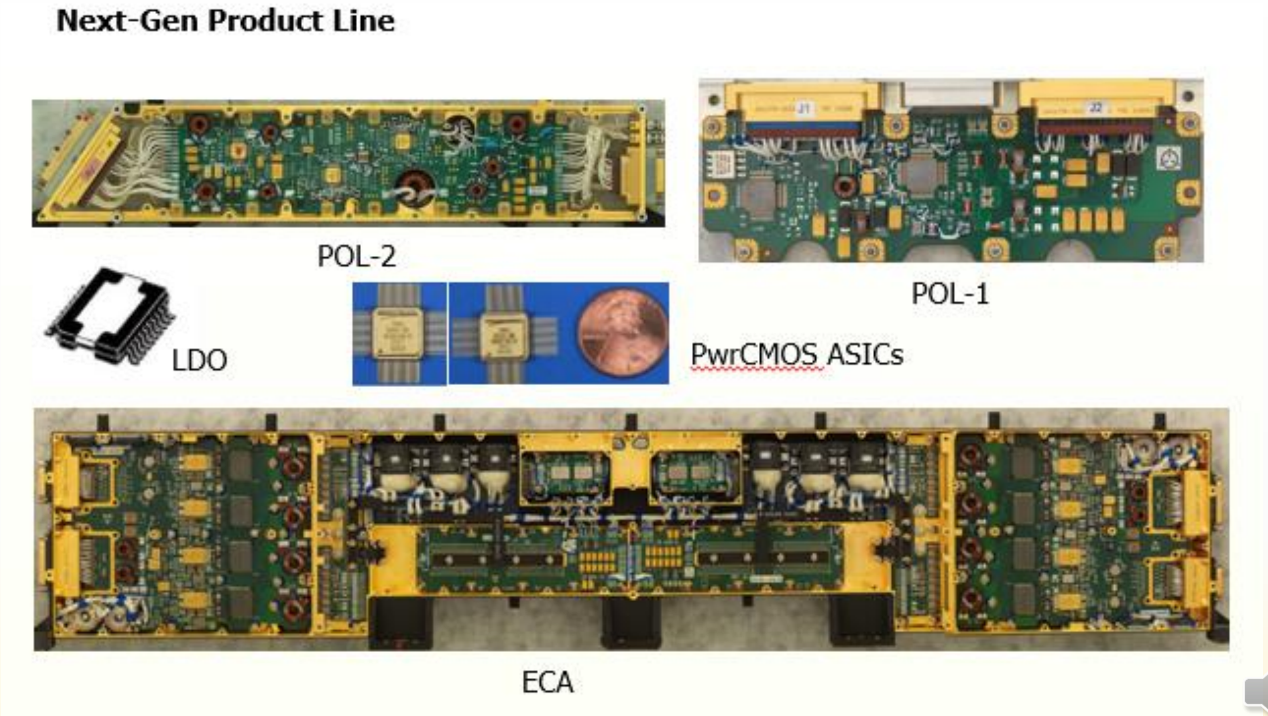
04
EM (Cycle)
A generic EM was built on IRAD to secure insertion tnto major programs

APOL Kudos: Voice of the Customer

APOL success was report to the highest level of the US Government ‘for significantly enhanced national security!’

Insertions

- Insertions into major programs and product lines
  - Payload-E
    - ECA
    - POLs
    - ASICs
  - P093
    - Many designs
  - CPC
    - Altima Comms
    - NASA GaN Amp



NORTHROP GRUMMAN